# Innovative approach to extracting flood events from continuous recorded streamflow records

**J. Janse van Rensburg [1], M Haw [1], A.H.M. Görgens [1], R Dube [2]**

[1] Ninham Shand Consulting Services (Pty) Ltd.
[2] Water Research Commission

### Abstract

A Water Research Commission study, conducted to derive a method for design flood hydrograph estimation based on the joint occurrence of flood peaks and flood volumes, is being undertaken. Development of the methodology will be based on the analysis of historically measured flood hydrographs, extracted from primary records of time and flow rates.

Manual selection of a large number of events from primary records is a laborious task, as well as being subjective.

A computer package was developed to assist in identifying and extracting complete flood hydrographs (peak, volume and shape) from DWAF recorded primary flow records. Flood event selection was based on a number of criteria or rules, which ensured that only significant flood events, in terms of peak, be selected. In addition, the start and end time of each significant flood event, were identified. With the start and end time available, the entire flood event could be extracted from the primary flow data. The rules further ensured the identification and selection independent flood events.

This paper will demonstrate the development, rules and application of the flood event extraction software using a range of South African flow records, as well as highlighting its potential use to other projects.

***Keywords:*** *Flood event, flood peak, volume, duration, flood event extraction.*

## 1 Introduction

The Dam Safety Office of the Department of Water Affairs and Forestry (DWAF) currently lists over 3700 dams in the Register of Dams. Potentially, all dams that are large enough to warrant listing on the Register pose some degree of public safety hazard. For this reason, dam safety legislation was promulgated in 1986, which prescribed the safety evaluation of all registered dams on a five-year cycle. The National Water Act of 1998 incorporated the original dam safety legislation.

SANCOLD (the South African National Committee on Large Dams) issued a set of Guidelines on Safety in Relation to Floods (SANCOLD, 1991), as well as a compendium of South African Design Flood determination techniques (Alexander, 1990), to provide guidance to those charged with evaluating the safety of existing dams, as well as the designers of new dams.

After the well-known HRU Report 1/72 on "Design Flood Determination in South Africa" (1972), the modification of the SCS technique for South African conditions by Schmidt and Schulze (1987), for small catchments, has been the only lasting development for the generation of complete design flood hydrographs for dam safety-related applications in the past 30 years or more. The need has been recognised to initiate research to bring the flood hydrograph-related information contained in the streamflow records of the last three decades into South African design flood practice. To this end, the Water Research Commission appointed Ninham Shand to undertake flood-related research with the following aims:

- To establish updated Guidelines for the safety evaluation of dams in relation to floods.
- To derive a methodology for design flood hydrograph estimation based on the joint occurrence of flood peaks and flood volumes, through analysis of historically measured flood hydrographs in all regions of South Africa.
- To develop a modernised set of design tools for the generation of complete flood hydrographs for dam safety evaluation or spillway design.

This paper deals with the approach developed for the identification and extraction of complete flood hydrographs (peak, volume and shape) from selected flow records for use in the development of a methodology for design flood hydrograph estimation based on the joint occurrence of flood peaks and flood volumes.

## 2 Flood Data Sources

### 2.1 Flood Data Availability

The Department of Water Affairs and Forestry (DWAF) executes its responsibility for streamflow monitoring in most South African river systems by building, instrumenting and maintaining streamflow gauges and recorders on these rivers. Due to the large number of potential gauges that needed to be examined as part of this study, it was decided, in order to economise on time and resources, to focus on an aggregate sample of flow gauges used in previous studies of design flood generation and safety in relation to floods. The main studies considered were:

- Design Flood Determination in South Africa (HRU, 1972)
- The Runhydrograph – Theory and Application for Flood Predictions (Hiemstra and Francis, 1979)
- The Standard Design Flood – Theory and Practice (Alexander, 2002).

The HRU (1972) used some 600 flood events from 96 gauging stations throughout South Africa. The main aim of the HRU was to produce unit hydrographs for the 9 generalised veld zone regions used to describe approximately homogeneous flood response zones.

After initially considering records from 123 stations, Hiemstra (1979) used flow records from 43 stations for his analysis. Stations were discarded after failing the statistical test for inclusion in the subsequent analysis, while some of the continuous flow record at a number of these gauges was too short (less than 10-15 years).

Alexander (2002) used flood data from 110 stations in the development of the Standard Design Flood. Since the SDF Method did not consider the flood hydrograph or flood volume, the database produced during development of the SDF only contained flood peaks (Alexander personal communication, February 2004). The database of flow gauges used in the SDF Analysis did not provide the specific information considered for use in this study. Extension of rating tables for those flow gauges for which the maximum flood levels exceeded the rating table limit, were generally done using slope-area calculations. These "extended" rating tables were however not official extensions of the DWAF rating tables and were therefore not included in the DWAF hydrological database.

A comparison of the flow gauges used by the above three studies however showed that the majority of flow gauging stations was either used or considered for use in all three abovementioned studies. Based on the assumption that the above studies would have covered the different homogeneous flood region of South Africa, the stations used in the previous studies were considered for use in this study.

### 2.2 Criteria used for screening of data

In order to select suitable flow gauging stations for inclusion in the flood event analysis of this study, the following first screening criteria were applied:

- **type of gauge** : stations measuring river flow or inflow to reservoirs only
- **length of record** : only streamflow records of longer than 15 years were considered
- **size of catchment areas** : gauges with catchment areas of less than 10km$^2$ were discarded
- **ability to record high flows** : the focus was on gauges which could record/register all or most of the high flow events at the gauging site, as well as for the rating table to cover the full range of recorded flood levels
- **reliable, complete records** : streamflow records with obvious errors in the data or known problems at the gauge were discarded, inclusive of records with long periods of missing values during the wet periods
- **upstream impact on recorded high flows** : streamflow gauges which had large in-stream reservoirs upstream of the gauge were discarded due to the possible attenuation of floods through reservoirs.

Of the 261 candidate gauges, only 102 gauges passed through this rigorous screening process and could be considered for further use in the study.

Figure 2.1 shows the location of the flow gauges selected by this study.


**Figure 2.1: Location of flow gauging stations**

# 3 Development of flood event extraction software

## 3.1 Introduction

The large number of flood events to be extracted from the primary records necessitated the development of a computer program to assist in identifying and extracting complete flood hydrographs from continuous recorded flow data. Apart from speeding up the laborious task of identifying flood events, application of the software would also ensure an objective, consistent and repeatable approach in identifying events for future analysis.

It should however be noted that the empirical rules employed in the software for event identification cannot cater for all different variations in flood hydrographs, hence a measure of user intervention and interaction was allowed for. Input to the extraction program is primary records (time, recorded level and flow rate) obtained from DWAF, while the following flood characteristics were extracted for each event:

- Flood peak and associated volume and duration
- Graphical representation of flood event hydrograph
- Writing the flood event to an Access database, with the option of writing hydrographs to ASCII/text format.

## 3.2 Rules for flood hydrograph identification and selection

The three main hydrograph selection criteria are:

- the identification of significant flood events, assisted by setting "truncation levels"
- start/end date/time of flood hydrographs
- extrapolation of rising and recession limbs to zero flow line.

### 3.2.1 Identification of significant flood events, by setting "truncation levels"

The overall focus of the study was on floods in relation to dam safety; hence the focus was on the extreme flood events. The approach followed during the abstraction process was therefore firstly to identify periods in the primary record that included significant flood events. Identification of significant flood flow events (in terms of peak) was achieved by setting a threshold or "truncation level", with only events higher than the truncation level considered. The truncation level therefore also aided in screening out minor events.

Using the "truncation level approach" resulted in a partial duration series of flood peaks above the "truncation" level for a specific gauge. The implication of setting truncation levels was that more than one event could potentially be selected from a "wet" year, while no events were selected from a "dry" year. The flood extraction software sets a default truncation level such that five peaks per year, on average, are selected. The advantage of the partial duration series over the annual maximum series is that it potentially produces three to five times more events (Flood Estimation Handbook, FEH, 1999).

### 3.2.2 Identification of independent events

Once selected, the Flood Estimation Handbook (FEH, 1999) method is used to verify that events are independent. This method assumed that if two peaks are close together, the highest is "independent", while the others relative to the highest are only independent if the two peaks are separated by at least three times the average time to rise, and if the minimum discharge in the trough between two peaks are less than two-thirds of the discharge of the first of the two peaks. The time to rise is taken as the time difference between the start of the rising limb and the peak on the hydrograph. Since the aim of the flood analysis was to derive a methodology for design flood hydrograph estimation based on the joint occurrence of flood peaks and flood volumes, the complete flood hydrograph (peak, volume and shape) was required for analysis. The base flow therefore forms part of the flood hydrograph and no base flow separation was therefore conducted after selection of the flood events.

### 3.2.3 Start/End time of flood hydrographs

The flood peak is easily identified, while calculation of the flood volume depends on the identification of the start and end time of the specific flood event.

The start date/time of a flood event is generally easily identified by physical inspection as the point where the hydrograph changes from near constant or declining values to rapidly increasing values. The approach followed in the software was to firstly identify the peak of the event, and to then "back-track" along the rising limb of the hydrograph to find the point where the slope of the rising limb is less than 5 $m^3/s/s$. The next step is to find the point along the rising limb where the angle between successive line segments changes to more than 25º. This second step was required as the slope option alone often identified early start dates.

The duration, shape and peak of the rising limb of a hydrograph are dependent on both storm and catchment characteristics. The recession limb is however largely independent of storm characteristics and is controlled by the hydraulic and storage characteristics of the catchment. Identification of the end of the flood event, which is when the flood flow has subsided and only base flow, which is not directly related to the causative rainfall for that event, remains in the river, is however not as easily defined.

After considering a number of approaches to determine the flood event end date/time, the eventual approach used in this study was based on the principles of the semi-log approach. The approach used in this study considered the difference in the change in angle of the recession curve between two successive flow points as the indicator. The procedure for identifying the end of the flood event is:

- Identify the start of the event, as the point where the hydrograph changes from near constant or declining to showing a rapid increase
- "Draw" a horizontal line across the time-flow graph until the recession limb of the hydrograph is intersected, forming a so-called "Pegram-event". A "Pegram-event" is simply that portion of the record period selected using the "horizontal line approach" and can often include more than one individual flood event, is demonstrated in Figure 3.1.

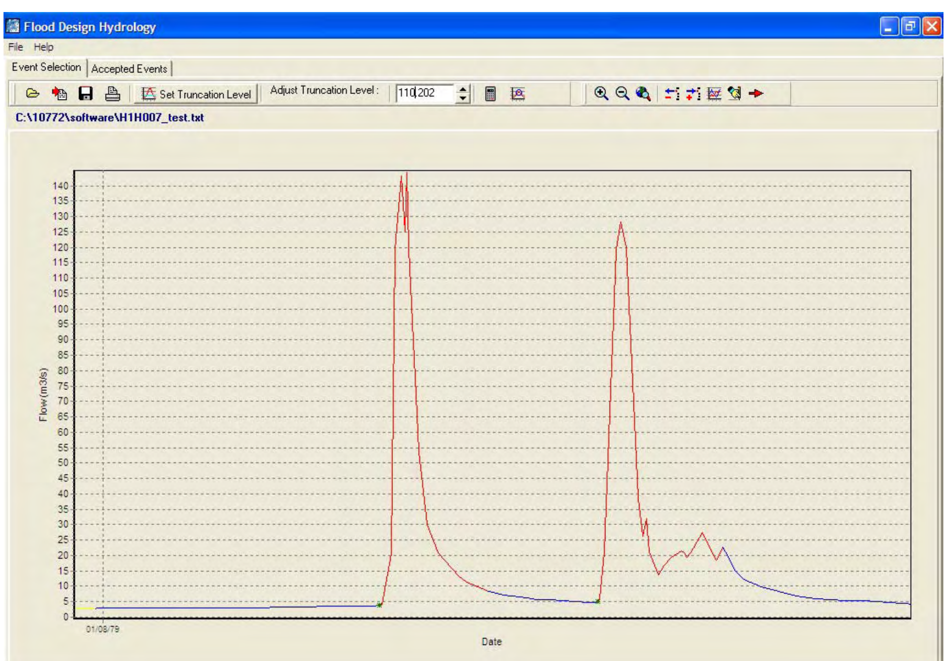


**Figure 3.1: Identification of a "Pegram-Event"**

- Set the preliminary end-date/time at 4.5 times the time-to-peak
- From this "start" point, move backwards, i.e. "up" the recession curve, seeking for 3 successive positive angles
- Set the end-date/time where the angle between successive line segments changes to more than 25º. This point identified is then assumed to be the end of the flood event. A change in angle of 25 degrees was accepted as a sound "indicator" after evaluating a range of flood events from four typical flow gauges

Figure 3.2 shows an event with varying flows on the recession limb, which demonstrates a scenario where the simple semi-log approach would be inadequate to determine the event-end date/time.

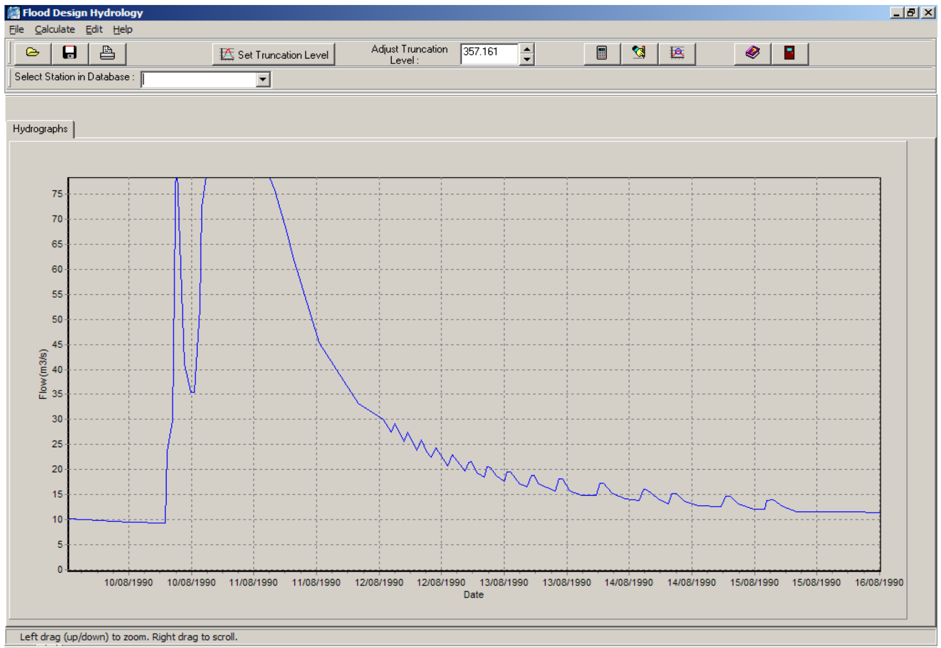


**Figure 3.2: Flood event with irregular recession limb**

It should be noted that the base flow contribution to the total volume of the flood event is generally less than 5%, hence the error made by selecting an inaccurate end-of-flood point will have little impact on the sample statistics of the total flood volume, as long as a sample of reasonable size is used.

Although the approach mentioned above is successful in flood hydrographs with smooth recession curves, many flood hydrographs have irregular recession curves, with multiple events occurring close together. A component for interactive user intervention was added to cater for those events not correctly identified by the automated process.

As a result of the identification and selection criteria described above (i.e. draw horizontal line across the hydrograph from the start to where it crosses the recession limb)

### 3.2.4 Extrapolation of Rising and Recession Limbs to Zero Flow Line

Since the start and end points of the flood hydrograph (as described above) are not at zero flow, the rising and recession limbs therefore have to be extrapolated to the zero line in order for the total flood volume to be calculated. Since the base flow is generally low compared to the peak of the event, it was decided to use a straight vertical line extrapolation from the start and end points of the event to the zero flow line, the argument being that this arbitrary extrapolation of the rising and recession limbs would not have a significant effect on the total flood volume.

# 4 Flood extraction software application

The following sections provide a brief demonstration and application of the flood event extraction software

## 4.1 User-interface

The software was developed in Delphi and uses a system of drop down menus (activated through buttons on the screen) and user interaction. The following functionality is available:

- **Load Data**: loads text files of primary data in DWAF (internet-based) format and produces a plot of the primary record for analysis.
- **Set Truncation level**: sets the truncation level such that approximately five events per year exceed the level. An option is also available for the user to manually adjust the truncation level.
- **Accept Events**: accepts the events in the hydrograph as accurately defined and allows the user to view the individual event characteristics.
- **Save events**: saves defined events. Files are saved to an Access database.
- **Print**: prints two versions of the plots on the Hydrographs sheet (one portrait orientation and one landscape orientation).
- **Calculate Runoff:** calculates total runoff for a user-defined period.
- **Load Events**: uploads events previously processed and saved by the program.
- **Help**: opens help files. (under development).
- **Quit**: closes the window and quits the program.

As a result of the nature of certain primary data sets, the software may select event start points (flow rates) that may be consistently too high or too low. The user can change these levels via the **Maximum start date level** button for that specific gauge.

Additional functionality include:

- **Zoom in and Zoom out**: zooming options.
- **Global zoom out**: zooms out to display the full record.
- **Delete series**: deletes the selected event.
- **Add series**: adds event to user-specified start and end dates.
- **Plot semi-log**: plots semi-log of active event in a window just below the hydrograph window.

The option is available to scroll up, down or side ways within the hydrograph window using the mouse.

## 4.2 Loading Data Files

### 4.2.1 Loading primary data files that do not require rating table extension

Figure 4.1 shows the results of loading primary flow data and allowing the software to select flood events with peaks above a certain truncation level.

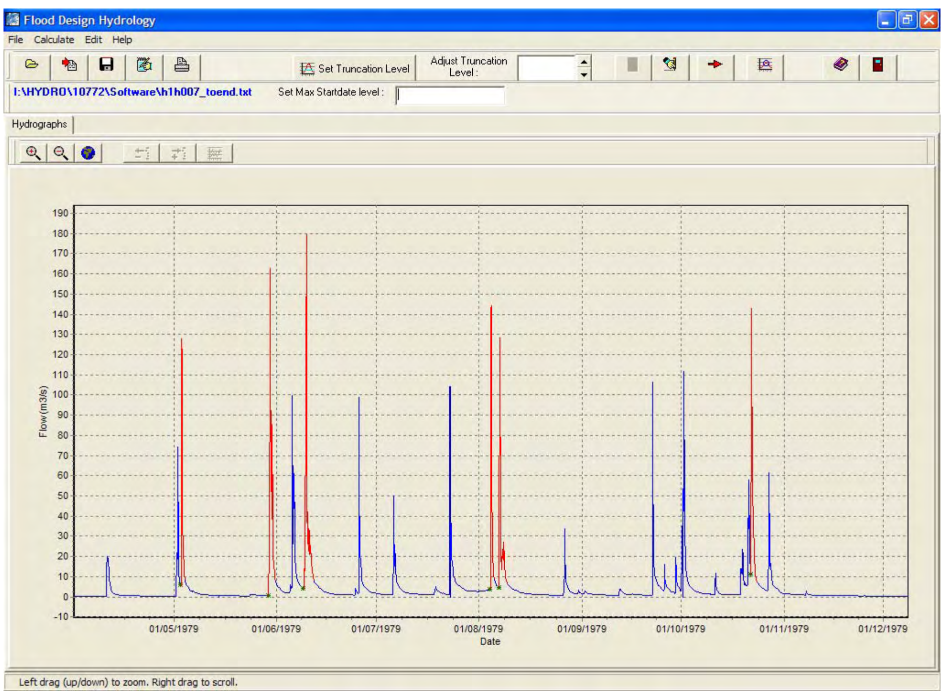


**Figure 4.1: Hydrograph window with Flood Events Selected**

### 4.2.2 Loading Primary data files that require rating table extension

As a result of limited flow gauging and rating table capacity, the recorded flood levels may exceed the rating table limit, but the primary flow data rates will be limited to rating table limit. In order to estimate flow rates for the levels above the rating table limit, an extension of the rating table is required. The software allows for a log-log extension of the rating table in these situations to estimate flow rates for levels higher than the rating table limit. The user required includes the number of rating tables that are exceeded, the start and end date applicable to that particular rating table, for each rating table, and the log-height and log-flow rate for the start of the extension (i.e. the rating table limit) and the end of the extension (i.e. the maximum observed level and the user-created extension for flow).

Figure 4.2 shows the input screen for entering rating table extension information.

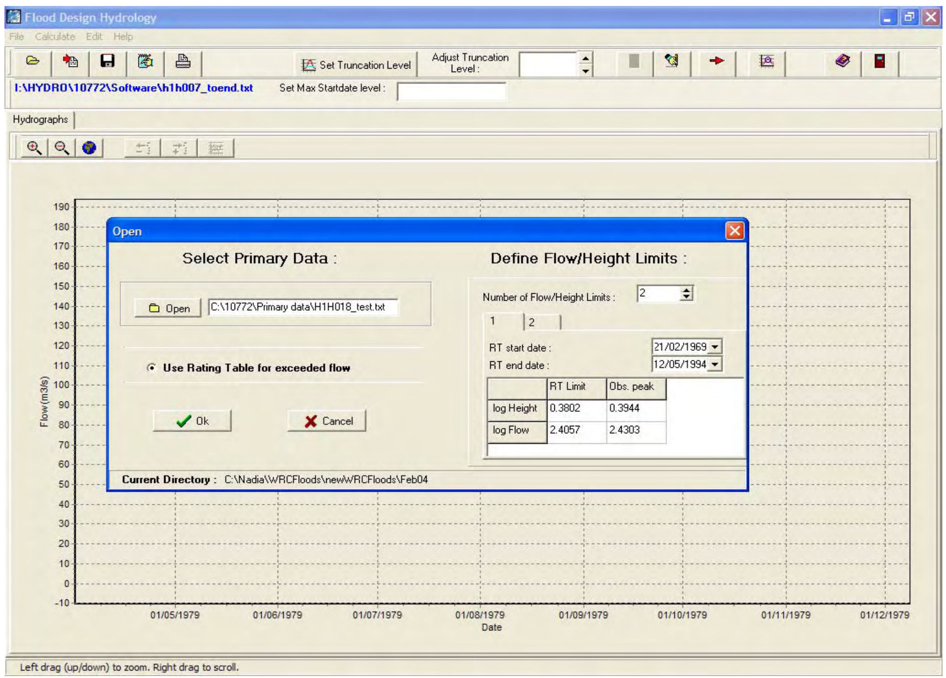


**Figure 4.2: Rating Table Extension Input**

## 4.3 Defining events

Once primary data is loaded and plotted in the hydrograph window, the program determines a truncation level (based on five events per year, on average, for the record period) and determines individual flood events. The following options are available to the user:

- Change the truncation level, if necessary.
- Calculate actual flood events. Calculated events are plotted in red over the full record (plotted in blue), while the start of am event is indicated with an asterisk.
- Due the non-uniform nature of primary data, the events defined by the software may not always be correct. It is therefore essential that the user briefly view each of the events in the context of the flow record to determine suitability.
- The user can adjust/correct events that are not accurate by selecting the specific event that need to be changed. The chosen event will show in yellow, with the option of changing either or both of the start and end dates.
- The semi-log plot function is a useful aid in choosing the correct end dates, as the change in angle in the recession limb of the hydrograph is more defined on the semi-log plot than on the linear scale hydrograph. The user can display a semi-log plot of the active graph, with the option of plotting multiple events.
- The user can add events not identified and selected by the software. New event is stored in internal memory and plotted over the blue base-line in red.
- Events incorrectly identified can be deleted. Deleted events are removed from internal memory and re-plotted in blue.
- The option is available to calculate the runoff for a particular period. It should be noted that this volume (in $Mm^3$) is for a selected period, which could span the full record period and not for a specific flood event.

Figure 4.3 shows the results of event selection, as well as the semi-log plot for the same period.

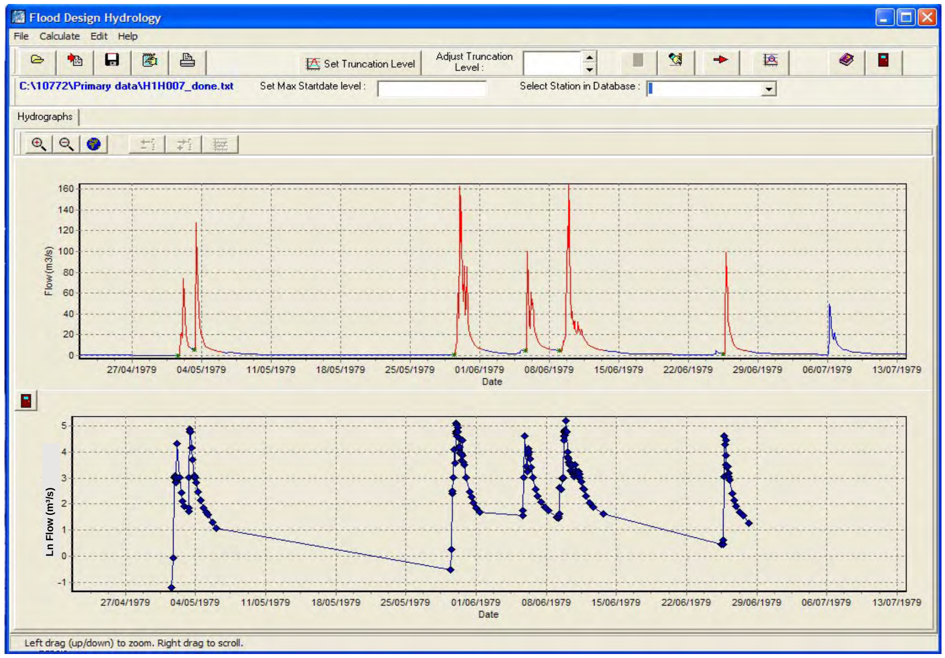


**Figure 4.3: Hydrographs and Semi-log plots**

## 4.4 Saving Events

This function allows the user to save events to be recalled into the program and confirmed at a later stage. The events are saved in a text file in a format specific to this program.

## 4.5 Accepting events

Events previously saved, but not accepted as final yet, are uploaded before finally accepting the event as correct. Once the user is satisfied with the accuracy of the start and end dates of the events, the function of accepting the events allows the user to view individual events and their characteristics (peak, volume).

By accepting the selected events, an additional sheet "Accepted Events" is activated. This sheet consists of five different windows containing the following information:

- **Stations**: a list of stations contained in the database
- **Pegram-events**: for each stations, a complete list of Pegram-events identified during the initial event selection process
- **Flood Events**: for each event forming part of a Pegram-event, a summary is given of the start and end date/time of the event, as well as the peak and flood event volume
- **Hydrograph**: For the specific event shown in the "Flood Events" window, the coordinates of the entire event, in date, time and flow rate format, is shown, as well as a graphical presentation of the selected event.

Figure 4.4 shows the "Accepted Events" window.

## 4.6 Writing Events

The option exists to write the accepted events to text file format, containing date and time of writing out, the start and end dates of events, peak (in $m^3/s$) and volume (in $Mm^3$) for each individual event, as well as the date, time and flow rate coordinate defining the selected flood event.

Table 4.1 shows an example of the text file format of an accepted event.

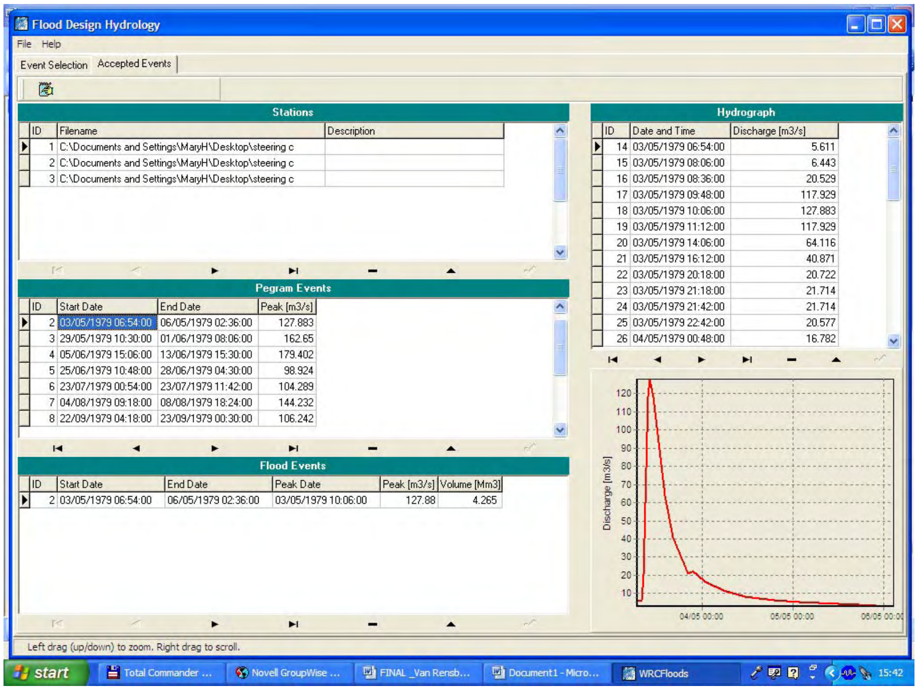


**Figure 4.4: Accepted Events Window**

**Table 4.1: Text file format of an accepted event**

| |
|---|
| H1H007A01 |
| Run Date : 10/08/2005 07:15:20<br>For number of events see bottom of file... |
| Start date : 03/05/1979 06:54:00<br>End date : 03/05/1979 21:18:00<br>Peak : 127.883 m3/s<br>Volume : 2.847 Mm3 |
| 03/05/1979 06:54:00 5.611<br>03/05/1979 08:06:00 6.443<br>03/05/1979 08:36:00 20.529<br>03/05/1979 09:48:00 117.929<br>03/05/1979 10:06:00 127.883<br>03/05/1979 11:12:00 117.929<br>03/05/1979 14:06:00 64.116<br>03/05/1979 16:12:00 40.871<br>03/05/1979 20:18:00 20.722<br>03/05/1979 21:18:00 21.714 |
| Number of events: 1 |

## 5 Conclusions

The flood event extraction software has the following benefits:

- It provides a repeatable, objective and consistent process of identifying flood events
- It creates a database of flood events, which can also be used for future studies
- It allows for a process that is more efficient to use than a manual approach
- User interaction is made possible in a friendly manner, as the existing event selection criteria do not cater for all possible flow variations and inconsistencies in the primary flow data.

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